OXC-6106-64

22 April 64

MEMORANDUM FOR THE RECORD

SUBJECT: OXCART Sonic Boom and Engine Noise Programs

1. During the period of 22 through 24 August 1963 sonic boom pressure measurements were obtained on eleven runs. Data points were from 41,000' MSL to 64,000' and 1.4 Mn to 2.15 Mn. Curves prepared by Dominic Maglieri of NASA are attached. Mr. Maglieri felt that the above data points were sufficient for the limited flight envelope at that time. Pressure measurements were taken directly under the aircraft and along a line at right angles to the flight path. Stations and observers were placed at intervals along this line. On the last test the farthest observer was 33 miles out.

2. In addition, Pratt & Whitney conducted engine noise measurements during the Fall of 1963. Their report titled "Noise Measurement" is attached.

3. Since the attached sonic boom data is limited in Mach number, steps are underway to schedule additional measurements for more meaningful data at higher Mach numbers.

Atts: As Stated

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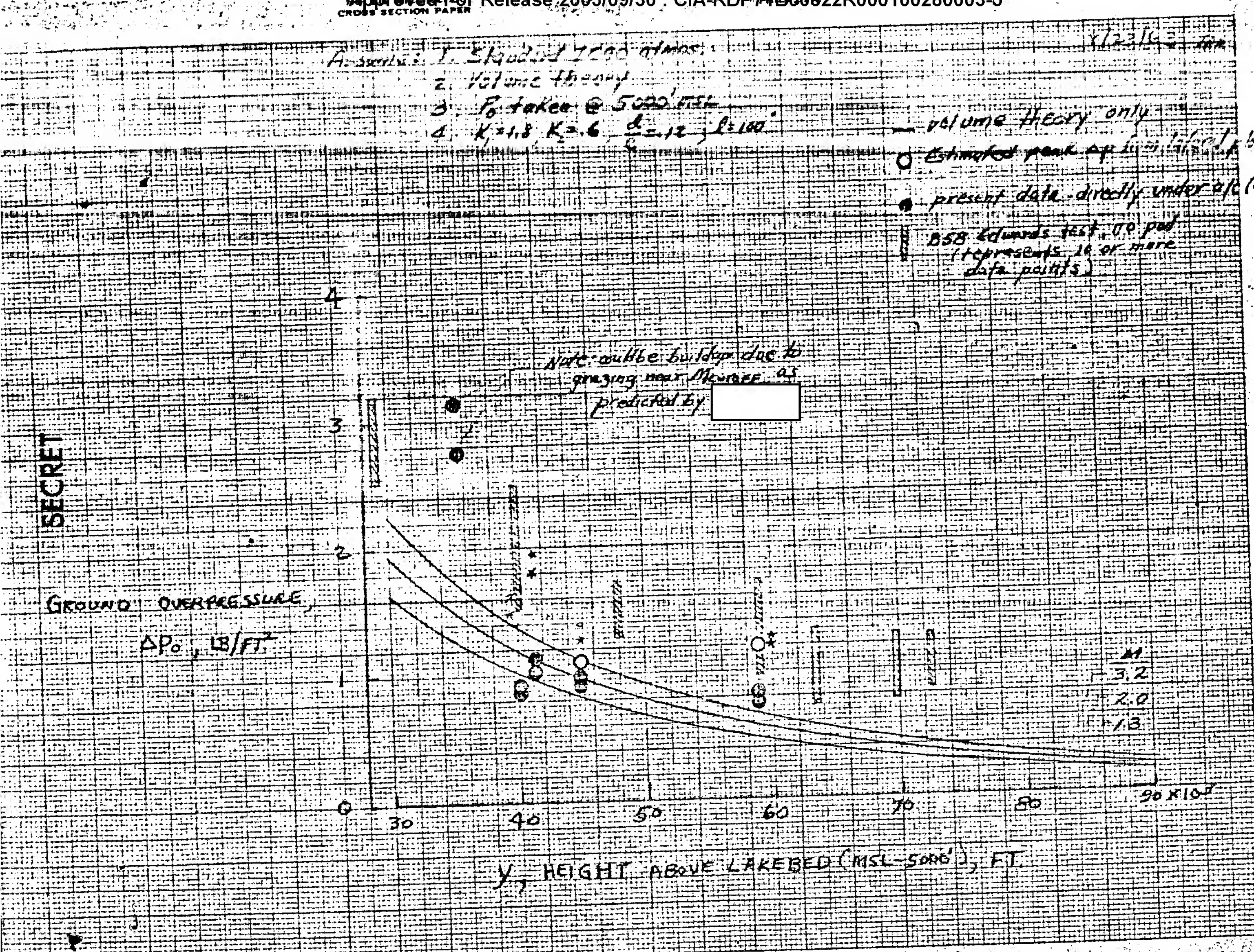

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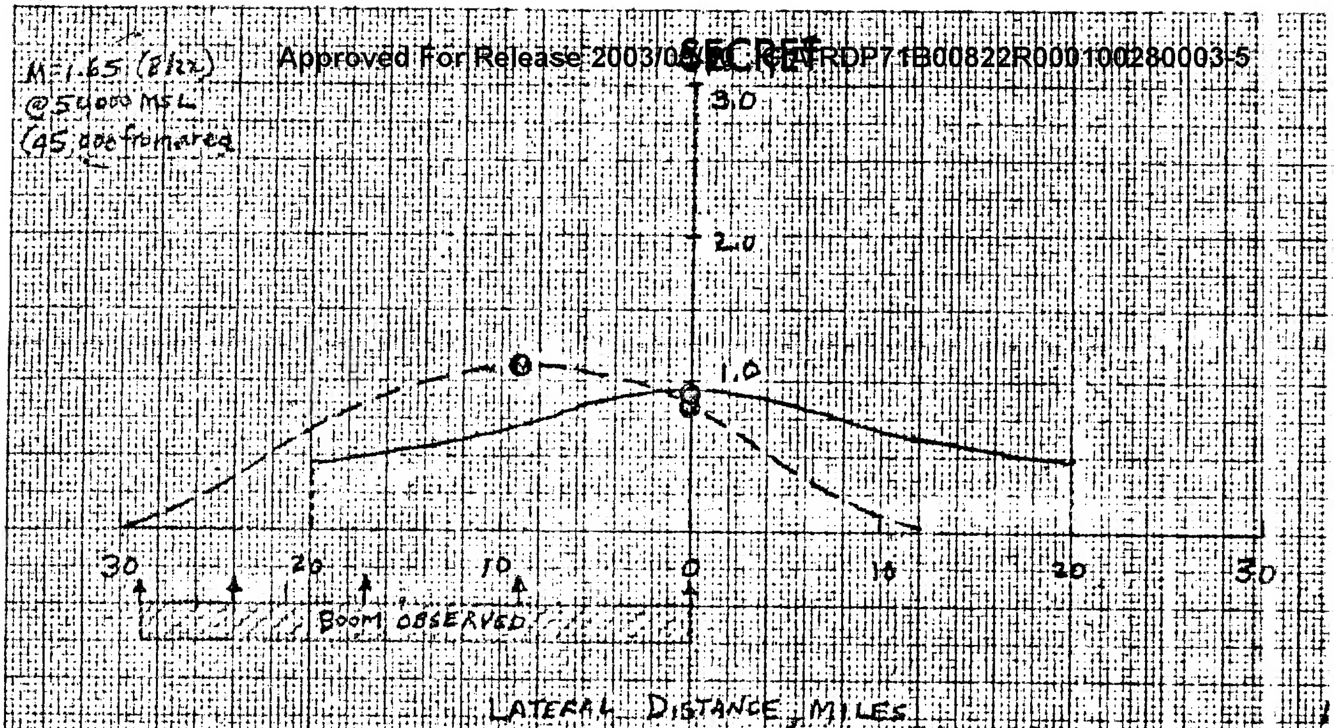
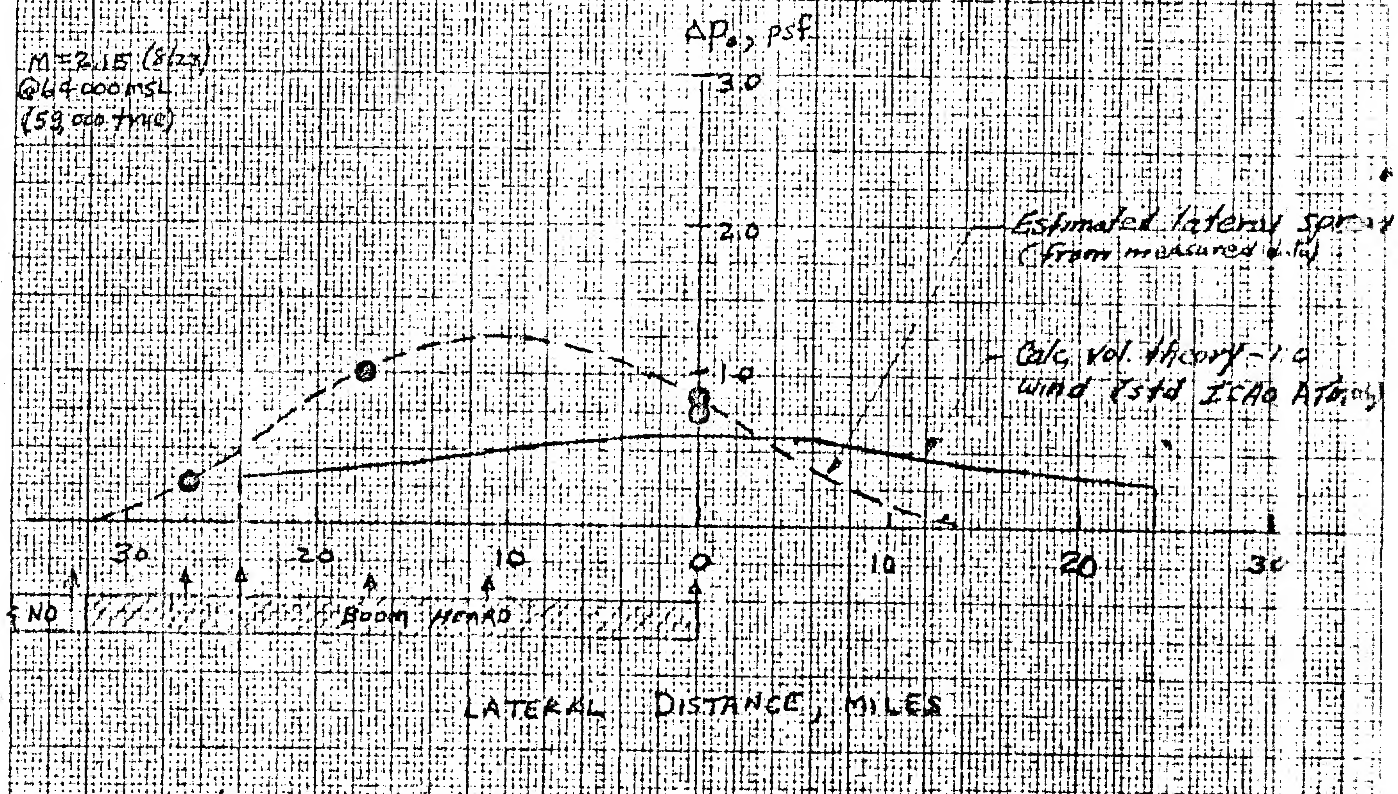
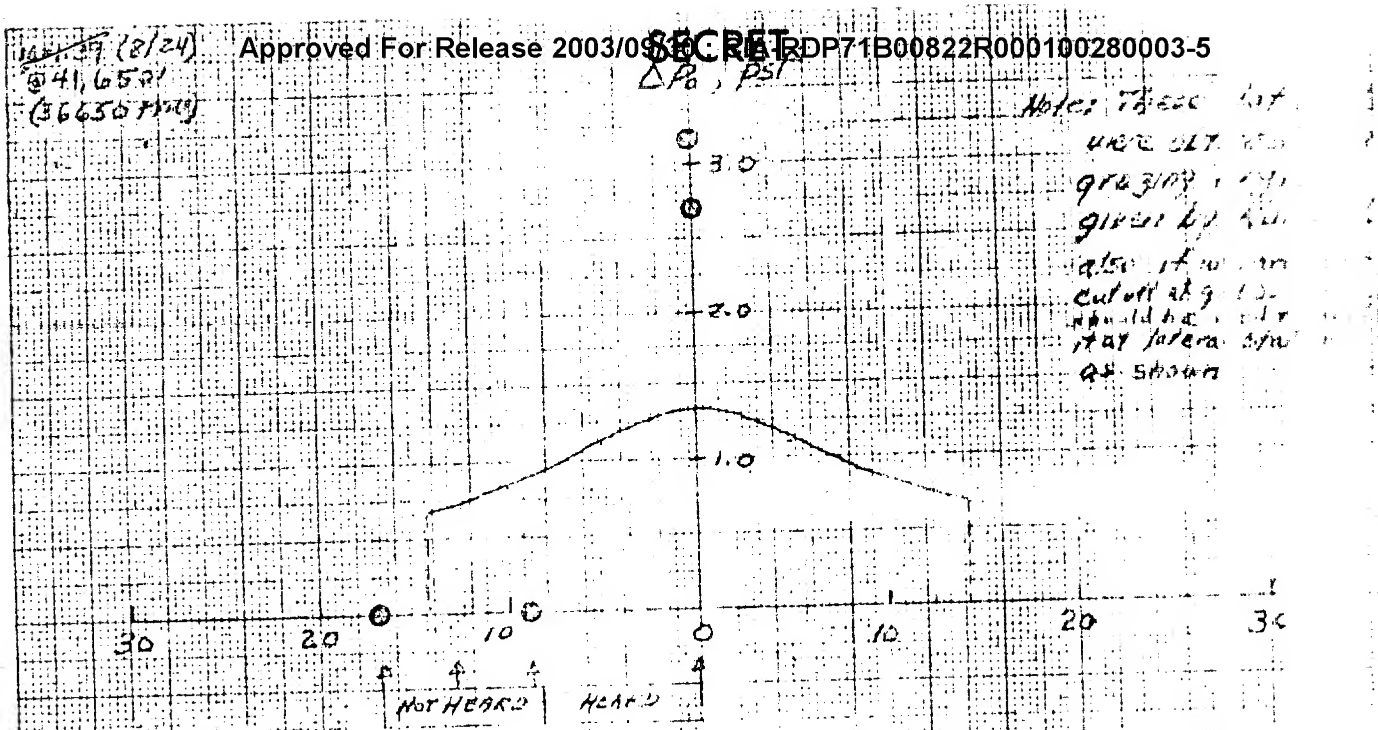
Note: to get a/c MSL altitude add 5000'



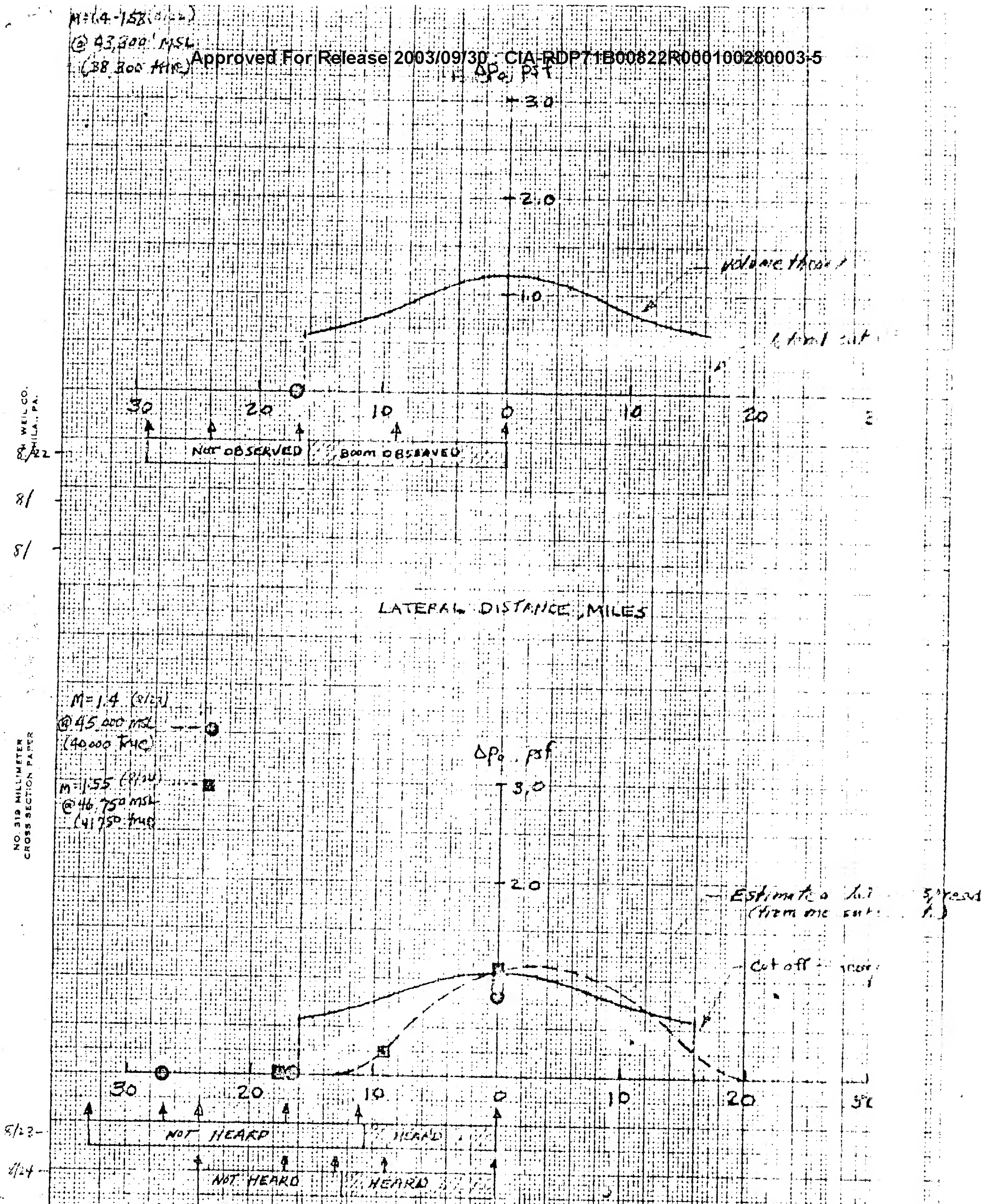


arrow indicates observed

Note: Estimated lateral cutoff based on true dist. to a/c.



(8/24)
@ 41,650'
(36650 ft)
ΔP_o, PSI
3.0
2.0
1.0
30
20
10
0
10
20
30
NOT HEARD
HEARD
Note: These ... were ... grazing ... given by ...
also if ... cutoff at ... should be ... stay latera... as shown



arrows indicate observer stations
Estimated cut off based on true dist. to a/c

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Attachment to
OXC-6106
COPY /

NOISE MEASUREMENT REPORT

October 1963

I. SUMMARY

Noise measurements were taken during flight testing of JT11 powered articles on September 12 - 14 and October 1 - 3, 1963. Take-off and landing operations were recorded. The following conclusions result from examination of the data.

Maximum afterburning take-off PNdb levels of noise for the flight article were greater by about 10 PNdb than currently operating commercial jet transports when compared on an equal altitude basis. However, considering the increased thrust rating, the PNdb levels were considerably less, by about 8PNdb, than might have been expected.

Jet exhaust noise of the installed engine under flight conditions was less by about 5 db overall sound pressure level (SPL) than that measured during ground testing of the bare engine without flight hardware. The ejector nozzle is suspected to be the reason for lower noise levels.

High power non-afterburning flyover noise was not significantly less in PNdb level than maximum afterburning take-off noise, due to a change in spectrum shape. The reasons for this behavior are not fully understood.

The nearly complete absence of compressor generated discrete frequencies during landing approach made the noise under these conditions much more acceptable than that of currently operating gas turbine transport installations. The effect of the flight inlet configuration are apparently responsible for this reduction in noise.

II. Test Results

Tabulations and graphic plots of the significant test results along with pertinent comparative data are attached in the order listed below.

It should be noted that frequently data is shown on the basis of one engine. The corrections for increased numbers of engines are:

2 engines add 3db or 3PNdb
4 engines add 6db or 6PNdb

Data marked Flight Test are for the article, and therefore, include installed configuration effects. Data marked Static Test are from JT11 ground test measurements made with bellmouth inlet and variable area nozzle, but without ejector nozzle.

Figure 1 A tabulation of significant test data and basic uncorrected noise analysis.

Figure 2 PNdb vs Engine Thrust - data shows PNdb at maximum T/O and part power conditions for the flight article compared with maximum take-off noise of other engines. All are assumed to be at the same altitude.

Figure 3 SPL vs Jet Noise Parameter - data shows noise during flight to be about 5db less than JT11 ground test results. Both static and flight data describe lines of different slope than empirical data from other P&WA engines.

Figure 4 PNdb vs Altitude - data shows the rate of decrease of PNdb with altitude and permits comparison of values from two other engines.

Figure 5 Narrow Band SPL vs Time - data shows greatly reduced discrete frequency components in flight article landing approach noise than current subsonic jets.

Figure 6 Standard Day Atmosphere Attenuations - tabulation of factors used in making calculations.

Figure 7 Technique for Measuring Flight Noise Spectra from Ground Test Measurements.

Figure 8 Sample Calculations for Extrapolating Flight Data to Normalized Conditions.

Figure 9 Slant distances for microphone locations used during Flight Tests.

Figure 10 SPL vs Octave Band - data shows different spectra during landing approach for JT4 engines installed in flight article and in a commercial transport.

III. Discussion

Figure 2 shows that a reduction in thrust of the JT11 engine in flight, from maximum T/O afterburning power to Military power will not substantially reduce the PNdb level. Below Military power, a significant reduction in PNdb appears to accompany a reduction in thrust. Examination of the spectra for the point plotted at 18500 lb. thrust and the 26000 lb. thrust point showed that the lower thrust spectrum had lower levels of noise in the first five octave bands, but higher levels of noise in the upper three octave bands than the maximum thrust point. Therefore, while overall sound pressure level was reduced significantly, the perceived noise level was not.

Comparison of flight test results with static ground test results shown on Figure 3 indicate the flight data to be about 5db quieter than the ground test data at comparable values of Wg^2V^6/A, a parameter based on the work of M. J. Lighthill. The slopes of the curves described by both flight and ground test data appear to be parallel to each other and less steep with increasing Wg^2V^6/A than the empirical curve derived from test results from other P&WA engines. Without additional test experience or theory to explain these results one can only speculate on the circumstantial evidence provided by the data that;

1) some basic feature of the engine design causes slopes of the lines to differ from what is obtained from other engines.

2) the features of the flight exhaust system produce some jet noise attenuation. This could be the effects of the ejector action.

The relationship of PNdb to altitude on Figure 4 may be used to cross correlate altitude required for the JT11 at maximum T/O thrust to equal the PNdb of two other engines. The rate of reduction of noise for the JT11 is approximately 6PNdb for each doubling of distance. If part power predictions are desired, an approximation can be made by plotting the 1000 ft. altitude value from Figure 2 and using the same slope as given for maximum T/O.

The landing approach recordings showed almost no discrete frequency content when analyzed by a narrow band filter system (General Radio 8% b.w. analyzer). Figure 5 shows

confirmed points from three tests. Note the only discernible points are clustered in the narrow time band of one second before and after overhead location. Outside of this band, the discrete frequency signals were indistinguishable in the background levels which were at least 15db below the comparitive JT3D discrete frequency levels shown.

Figure 10 was drawn to compare JT4 engine spectra in commercial transports with that in the flight article during landing approach. The most significant feature of this octave band data is the great reduction in noise in octaves 6, 7 and 8. These octaves are where the compressor blade passing noise, or whine, frequencies exist. Narrow band analysis of the same data, although somewhat difficult due to Doppler shift of frequencies, confirmed personal observations that a great difference existed here. A commercial transport landing made at Idlewild Airport in New York showed a strong "spike" at a frequency of about 2200 cps which rose about 15db above the broadband noise levels. Similar examination of the flight article noise showed no 'spike" at all.

Instrumentation used for data acquisition and reduction was similar to that used in other P&WA field tests. The system was comprised of four channels of Altec BR-150 microphones playing into two, two-channel Magnacord tape recorders. The four microphones were placed so that noise directly under the article could be measured, as well as noise at lateral (to the side) distances of 150 ft., 300 ft., and 500 ft. Analysis instrumentation consisted of a tape playback system into a General Radio Graphic Level Recorder. Standard octave band filters were used for broadband analysis, while a narrow 8% bandwidth filter was used to obtain discrete frequency levels.

Symbol definitions

SPL - sound pressure level in decibels

$$\text{db-decibels} = 20\ \ln_{10} \frac{\text{sound pressure}}{0.0002}$$

where 0.0002 dynes/Cm^2 is the sound pressure of the lowest audible sound

PNdb - perceived noise level = sound pressure level adjusted to account for the level of sound in each octave band.

$\frac{Wg^2V^6}{A}$ – Jet noise correlation parameter

Wg = total exhaust gas flow – lb/sec

V = relative exhaust velocity – ft/sec

A = exhaust area – ft^2

Figure 1

DATE	REC. NO.	FLIGHT NO.	TEST MODE	ALT. FT.	IAS KNOTS	ROTOR SPEED RPM obs.	TEMP. °F amb.	REL. HUMID %	WIND mph	THRUST LBS	JET NOISE PARA. $\frac{M^2 V^6}{A}$	MIKE NO.	MIKE LOC. DIST. FROM FLT. PATH FT.	O/A SPL db	PEAK OCTAVE BAND SPL 1 db	2 db	3 db	4 db	5 db	6 db	7 db	8 db	PEAK PNdb	PEAK DISCRETE FREQ. SPL-db
9-12-63	1	121-80	Take-Off	250	250	6940	82	26	Calm	26600	$6.5x10^{24}$	1	500	122.6	114.0	112.0	115.5	118.5	114.0	109.0	103.0	94.0	129.5	
												2	300	127.4	112.5	118.0	124.5	120.0	117.5	113.0	107.5	98.5	133.5	
												3	150	129.4	116.0	122.5	125.0	123.0	119.0	117.0	111.5	105.5	136.5	
												4	0	131.5	116.0	123.0	126.0	126.0	123.0	120.5	115.5	109.0	140.0	
10-01-63	6	121-84	Take-Off	965	370	6910	85	12	Var	27200	$6.2x10^{24}$	1	500	114.9	96.0	108.5	110.5	108.5	106.0	101.0	91.0		121.0	
												2	300	120.2	107.0	115.5	115.0	112.5	110.5	105.0	99.0	90.0	126.0	
												3	150	120.5	105.5	116.0	114.5	114.0	110.5	106.0	97.5	85.5	126.2	
												4	0	120.0	104.5	115.5	115.0	113.5	108.0	105.0	96.5		126.0	
10-01-63	7	1001-8	Take-Off	320	370	7070	87	12	Var	24300	$2.4x10^{24}$	1	500	120.3	106.5	105.5	114.5	116.5	113.0	108.0	102.0	94.0	128.0	
												2	300	125.9	114.3	114.0	123.5	118.0	115.5	112.0	106.0	96.0	132.5	
												3	150	129.6	117.5	122.5	123.0	124.0	121.0	119.0	114.0	108.0	138.0	
												4	0	126.8	115.5	121.5	120.0	120.5	117.3	115.0	109.0	101.0	134.5	
10-02-63	12	126-22	Take-Off	490	360	7010	86	12	NE-8	31500	$6.6x10^{24}$	1	500	118.5	99.5	110.5	113.0	113.5	111.0	106.5	98.5		125.5	
												2	300	121.7	106.5	117.0	115.0	116.5	111.0	106.5	100.0	90.5	128.0	
												3	150	123.9	109.0	119.0	116.5	119.0	113.5	110.0	102.5	93.5	130.5	
												4	0	123.8	109.5	118.0	118.0	118.5	113.0	110.0	102.5	92.0	129.5	
10-03-63	16	126-23	Take-Off	600	260	6790	62	35	Calm	27760	$6.2x10^{24}$	3	0	124.5	111.5	119.0	118.0	119.0	115.0	111.5	106.5	99.5	132.0	
9-14-63	4	121-81	Military Power	1130	305	6940	82	26	W-6	18920	$1.1x10^{24}$	1	500	112.3	96.5	102.5	104.0	108.0	105.5	102.5	95.5	80.5	120.5	
												2	300	112.9	97.0	104.0	104.0	108.5	106.5	102.0	94.0	79.5	121.0	
												3	150	113.3	98.0	108.0	106.5	105.0	106.5	102.0	96.0	84.0	121.0	
												4	0	114.1	99.0	109.0	105.5	106.5	107.5	104.0	97.5	84.0	122.0	
10-01-63	8	1001-8	Military Power	865	325	7070	87	12	Var	13500	$1.5x10^{23}$	1	500	108.3	93.0	100.5	103.5	101.5	101.5	96.0	84.0		115.0	
												2	300	111.5	98.5	103.0	107.0	104.5	104.5	100.0	90.0		120.5	
												3	150	113.5	100.5	109.0	108.0	104.0	106.0	101.0	89.0	73.0	119.5	
												4	0	112.7	101.5	108.0	106.0	103.0	105.0	102.0	92.0		120.0	
10-02-63	13	126-22	Military Speed	590	330	6960	86	11	E-6	20000	$7.8x10^{23}$	1	350	115.0	96.5	106.0	109.0	107.0	110.5	104.5	96.0	82.5	122.5	
												2	150	115.0	100.5	109.5	107.0	108.5	108.0	104.5	94.5	78.0	122.5	
												3	0	114.6	102.5	110.0	107.5	107.0	107.0	102.5	98.0		121.0	
												4	150	114.6	104.0	108.0	109.0	106.0	106.5	101.5	90.5		120.0	
9-14-63	5	121-81	Landing	415	200	6400	82	26	W-6	5930	$2.0x10^{21}$	1	500	86.5	80.0	78.0	[illegible]	79.5	78.5	76.5	68.0		94.5	
												2	300	90.4	85.0	79.0	85.0	80.5	81.5	79.5	72.0	56.5	98.0	
												3	150	90.7	84.0	83.0	84.5	82.0	81.0	81.0	75.5	64.0	99.0	
												4	0	94.2	85.0	87.5	87.0	86.0	85.5	86.0	81.5	70.5	104.0	79.0
10-01-63	9	1001-8	Landing	490	210	6820	87	12	Var	5780	$3.2x10^{21}$	1	500	93.9	85.0	85.5	89.0	86.0	85.5	83.5	74.0		102.0	
												2	300	97.8	89.5	93.0	90.0	90.0	88.4	86.0	76.0	61.5	106.5	
												3	150	99.1	92.5	93.0	92.0	89.0	89.5	89.5	81.0	70.5	107.5	
												4	0	97.2	88.0	91.0	91.5	88.0	87.0	89.0	78.5		106.0	72.0
10-02-63	14	125-17	Landing	475			86	11	E-6			1	500	97.0	85.5	87.5	91.0	90.0	89.5	91.5	76.5	63.5	107.5	
												2	300	97.0	87.5	91.0	89.0	88.0	87.5	90.5	76.0		106.5	
												3	150	100.1	96.5	91.0	93.5	90.0	88.5	87.0	75.5	62.0	106.0	
												4	0	97.2	90.0	91.0	90.0	87.5	87.0	89.5	75.0		106.0	65.0
10-03-63	18	126-23	Landing	290	185	5540	81	15	Calm	3200	$6.0x10^{19}$	3	0	100.6	92.5	94.0	93.5	92.0	91.5	92.5	86.0	75.5	110.5	82.0

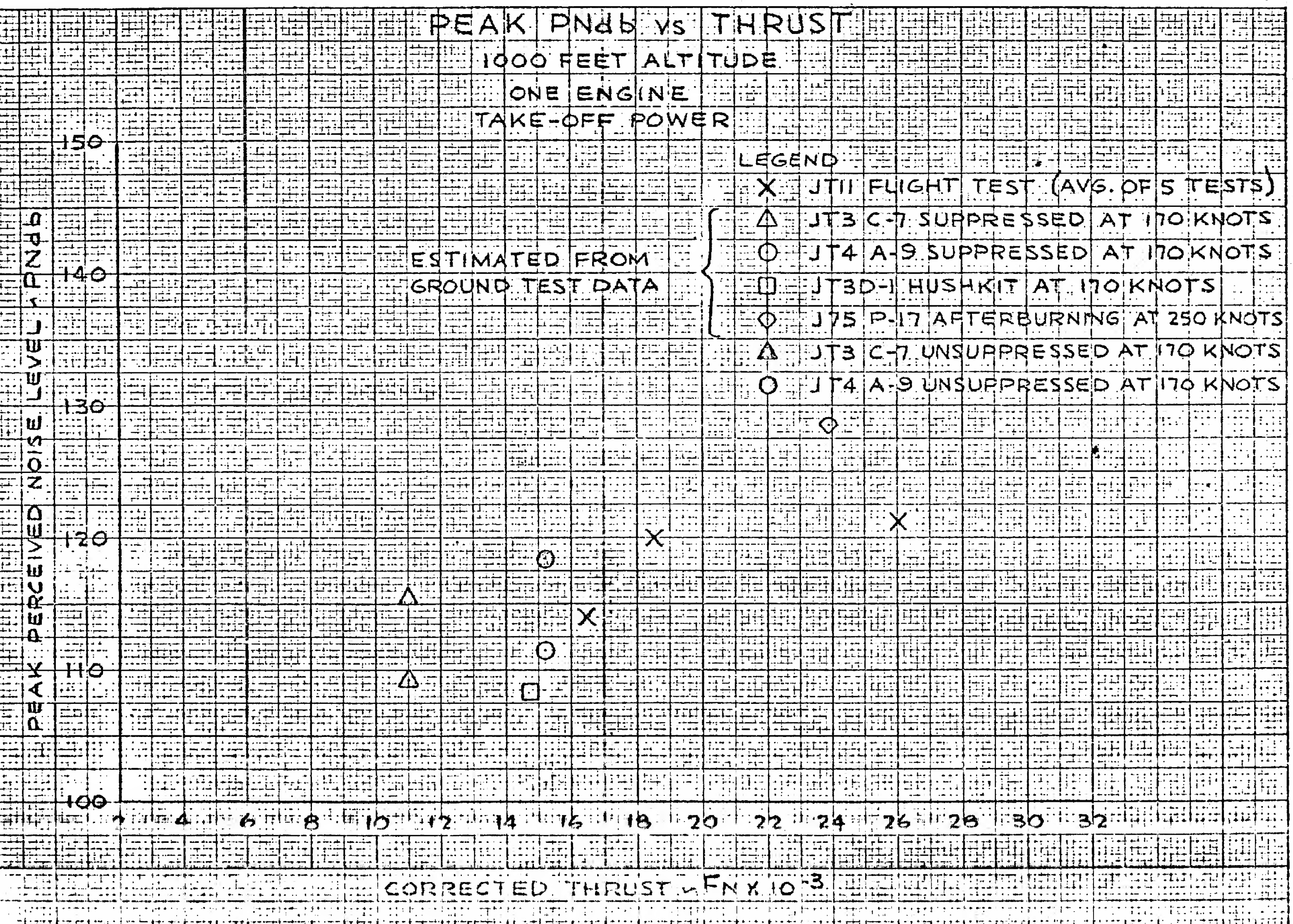

PEAK PNdb vs THRUST
1000 FEET ALTITUDE
ONE ENGINE
TAKE-OFF POWER
LEGEND
JT11 FLIGHT TEST (AVG. OF 5 TESTS)
JT3 C-7 SUPPRESSED AT 170 KNOTS
JT4 A-9 SUPPRESSED AT 170 KNOTS
JT3D-1 HUSHKIT AT 170 KNOTS
J75 P-17 AFTERBURNING AT 250 KNOTS
JT3 C-7 UNSUPPRESSED AT 170 KNOTS
JT4 A-9 UNSUPPRESSED AT 170 KNOTS
ESTIMATED FROM GROUND TEST DATA
PEAK PERCEIVED NOISE LEVEL ~ PNdb
150
140
130
120
110
100
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
CORRECTED THRUST ~ Fn x 10⁻³

FIGURE 2

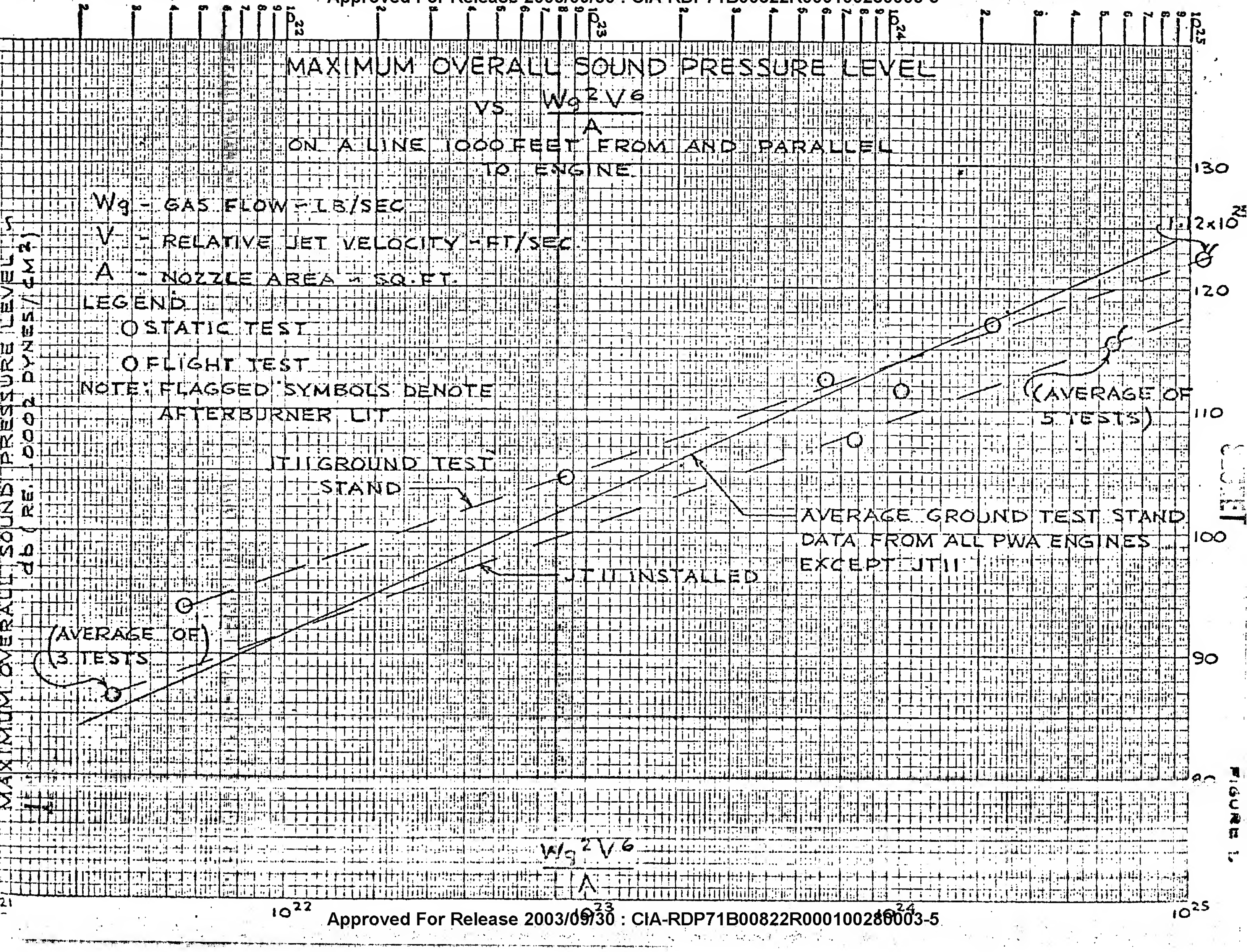

MAXIMUM OVERALL SOUND PRESSURE LEVEL
VS. $\frac{W_g^2 V^6}{A}$
ON A LINE 1000 FEET FROM AND PARALLEL TO ENGINE
W_g - GAS FLOW - LB/SEC
V - RELATIVE JET VELOCITY - FT/SEC
A - NOZZLE AREA - SQ. FT.
LEGEND
O STATIC TEST
O FLIGHT TEST
NOTE: FLAGGED SYMBOLS DENOTE AFTERBURNER LIT
JT11 GROUND TEST STAND
AVERAGE GROUND TEST STAND DATA FROM ALL PWA ENGINES EXCEPT JT11
JT11 INSTALLED
(AVERAGE OF 3 TESTS)
(AVERAGE OF 5 TESTS)
1.12×10^{25}
MAXIMUM OVERALL SOUND PRESSURE LEVEL db (RE. .0002 DYNES/CM²)
130
120
110
100
90
80
10^{22}
10^{23}
10^{24}
10^{25}
$\frac{W_g^2 V^6}{A}$

FIGURE 1.

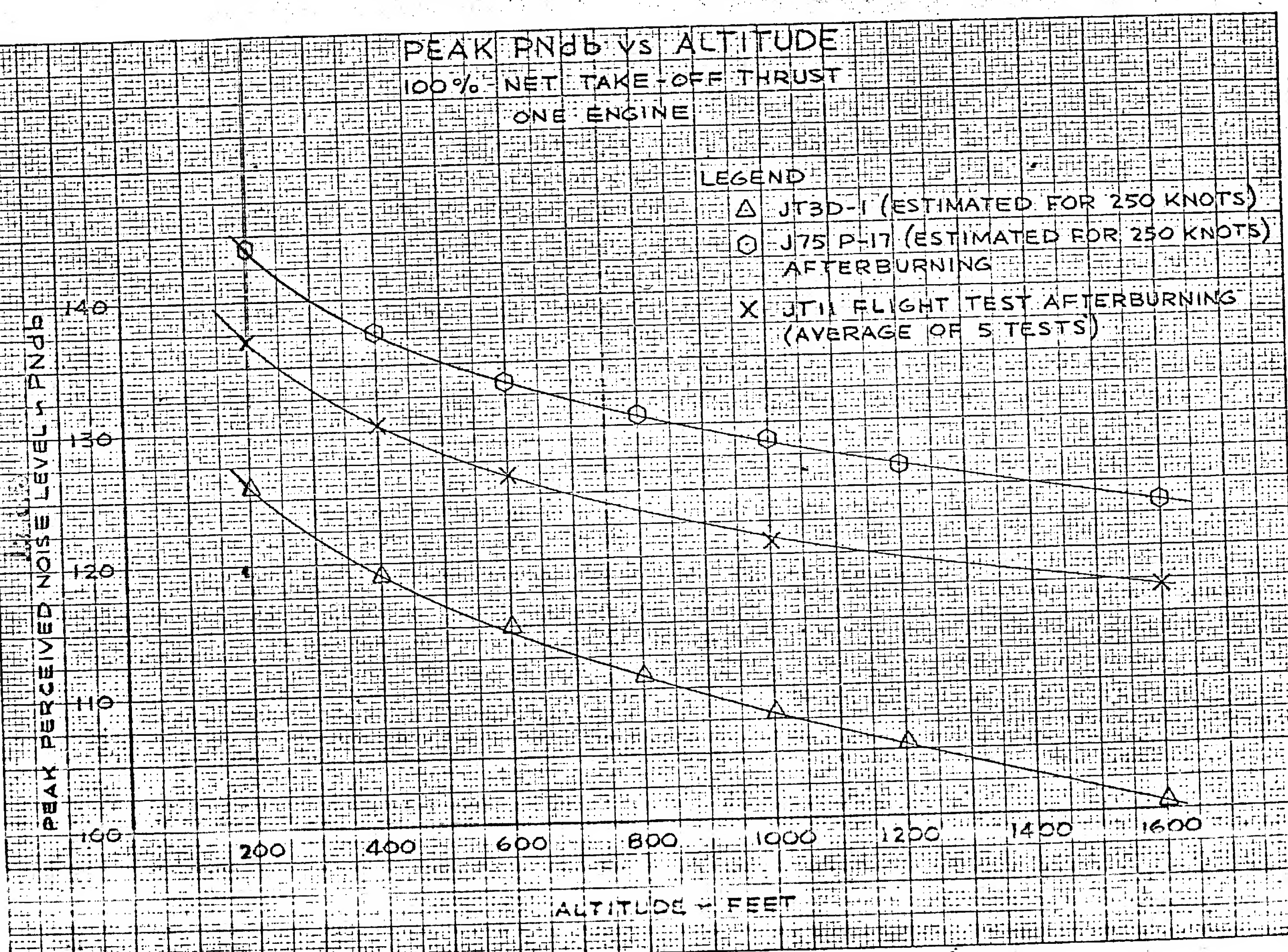
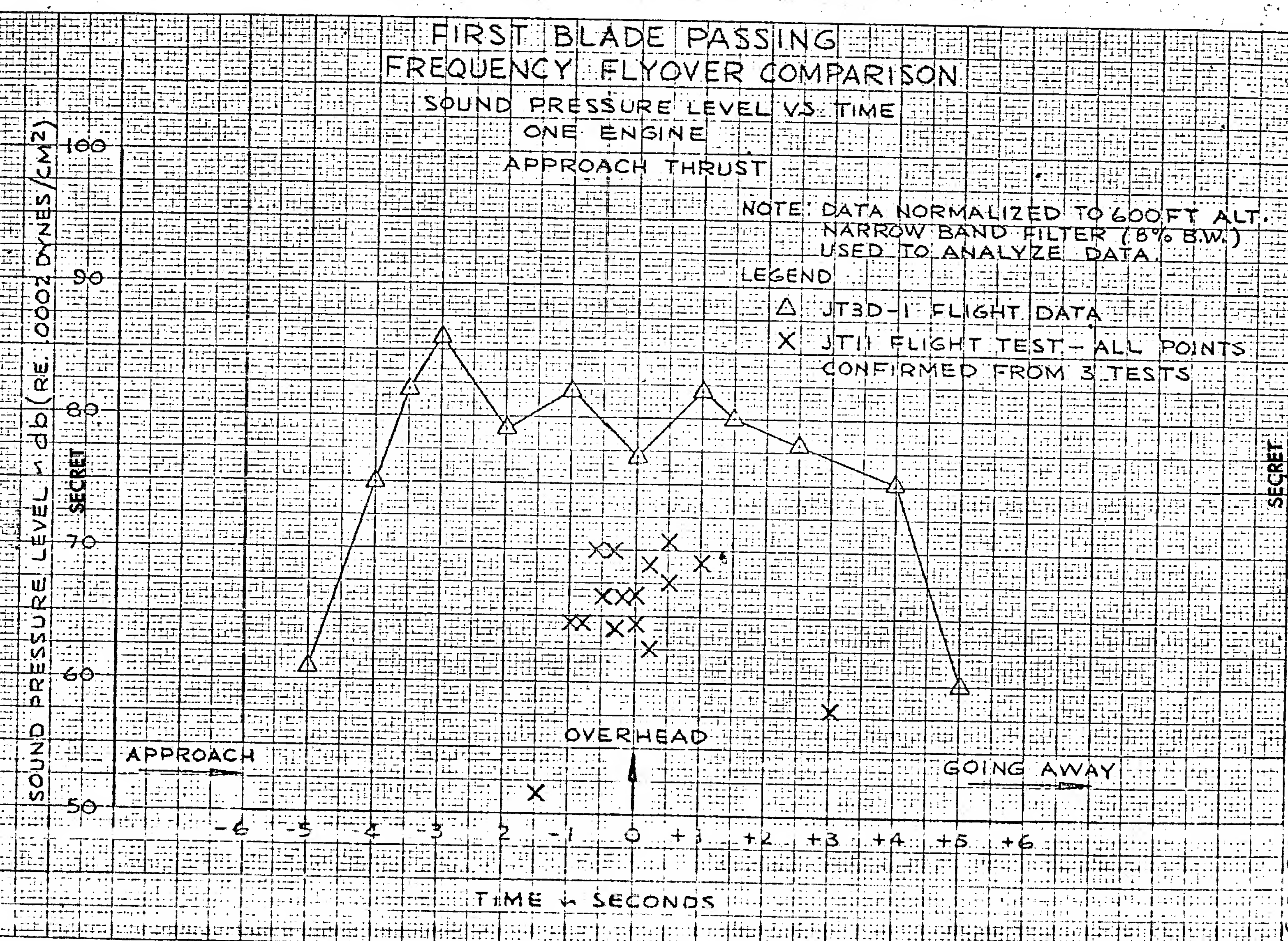

PEAK PNdb vs ALTITUDE
100% NET TAKE-OFF THRUST
ONE ENGINE
LEGEND
△ JT3D-1 (ESTIMATED FOR 250 KNOTS)
⬡ J75 P-17 (ESTIMATED FOR 250 KNOTS) AFTERBURNING
X JT11 FLIGHT TEST AFTERBURNING (AVERAGE OF 5 TESTS)
PEAK PERCEIVED NOISE LEVEL ~ PNdb
140
130
120
110
100
200
400
600
800
1000
1200
1400
1600
ALTITUDE ~ FEET

FIGURE 4



FIRST BLADE PASSING
FREQUENCY FLYOVER COMPARISON
SOUND PRESSURE LEVEL VS. TIME
ONE ENGINE
APPROACH THRUST
NOTE: DATA NORMALIZED TO 600 FT ALT.
NARROW BAND FILTER (8% B.W.)
USED TO ANALYZE DATA.
LEGEND
△ JT3D-1 FLIGHT DATA
X JT11 FLIGHT TEST - ALL POINTS CONFIRMED FROM 3 TESTS
SOUND PRESSURE LEVEL ~ db (RE. .0002 DYNES/CM²)
100
90
80
70
60
50
APPROACH
OVERHEAD
GOING AWAY
-6 -5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5 +6
TIME ~ SECONDS
SECRET
SECRET

FIGURE 5

STANDARD DAY ATMOSPHERE ATTENUATIONS

(Extra Air Attenuation)

Note:
Standard Day Conditions are 59°F and 70% Relative Humidity.

OCTAVE	FREQUENCY	EXTRA AIR ATTENUATION, db/1000'
1	37-75	0
2	75-150	0.1
3	150-300	0.2
4	300-600	0.3
5	600-1200	1.0
6	1200-2400	3.0
7	2400-4800	7.0
8	4800-9600	17.0

Technique for Estimating Flight Noise Spectra from Ground Test Measurements

Example (using JT3D noise data):

Problem
Find the composite peak noise spectrum for a JT3D engine at takeoff power, 170 knots IAS, 1000' altitude.

NOTE
Experience has shown at at takeoff power for JT3D engines, jet noise from the primary exhaust controls the peak levels of octave bands 1-6. Jet noise varies principally with jet velocity. Octaves 7 and 8 are controlled by fan compressor noise which varies principally with N_1 speed.

1. Obtain engine performance specifications for the JT3D engine covering the thrust range.

2. Measure noise at all octave bands on a 150' arc about the JT3D engine at several thrusts.

3. Calculate primary jet velocities using the formula $V_j = F_n/W_g \times g$ for each point in (2).

4. From (1) and (2) above, curves of sound pressure level db versus primary jet velocity are plotted for octaves 1-6 for a line (altitude) parallel to and 200' from the engine.

5. Curves of SPL db versus N_1 speed are plotted for octaves 7 and 8 for an altitude of 200'.

6. From (1), the primary stream, relative jet velocity and N_1 speed is found for the particular flight takeoff conditions stated in the problem.

7. The curves (4) and (5) are entered at the appropriate V_j and N_1 values to obtain a composite noise spectrum of peak octave band levels for a 200' altitude.

8. The spectrum in (7) is extrapolated to 1000' altitude using standard spherical divergence and extra air attenuation rates.

NOTE
Calculating takeoff flight spectra for most turbojet (as opposed to turbofan) engines is similar, but somewhat more simple. All 8 octave bands are controlled by jet exhaust noise in that case.

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Subject:
Sample calculation showing extrapolation of basic data from 250 ft. altitude to 1000 ft. altitude.

Octave	(1) Sound Pressure Level data point at 250 ft.	(2) Inverse Square Law (distance correction for spherical divergence) 250 ft. to 1000 ft. $20 \text{ Log} \frac{D1}{D2} = 20 \text{ Log} \frac{1000}{250} = -12$	(3) Extra Air Attenuation (P&WA) Δ db/1000 ft.	(4) Extra Air Attenuation 250 ft. to 1000 ft. $3 \times \frac{750}{1000}$ to nearest 0.5 db	(5) Sound Pressure Level at 1000 ft. 1 + 2 + 4
1	116.0	-12.0			104.0
2	123.0	-12.0			111.0
3		-12.0			114.0
4		-12.0			114.0
5		-12.0	-1.0	-1.0	110.0
6		-12.0	-3.0	-2.5	106.0
7		-12.0	-7.0	-5.5	98.3
8		-12.0	-17.0	-12.5	84.5

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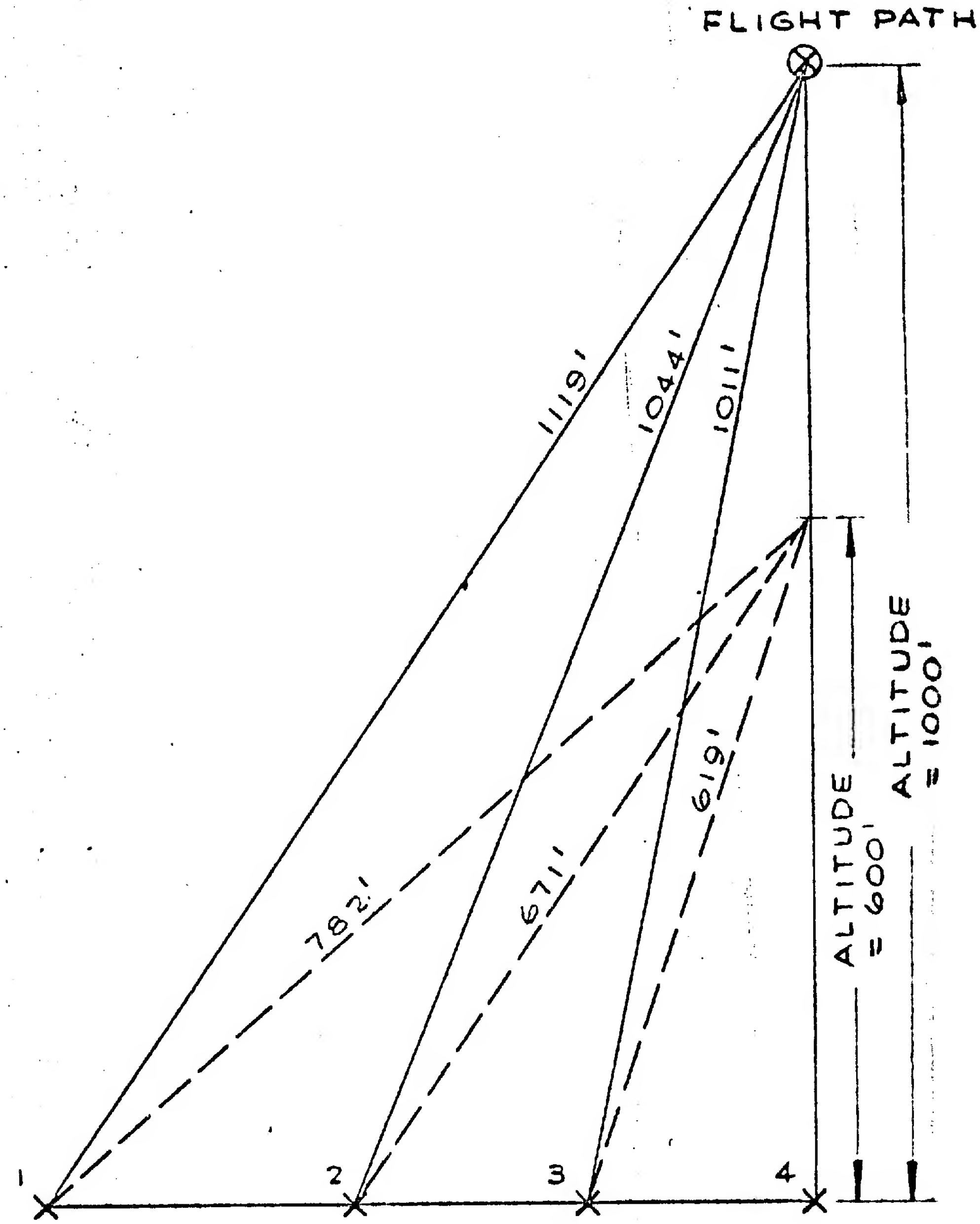
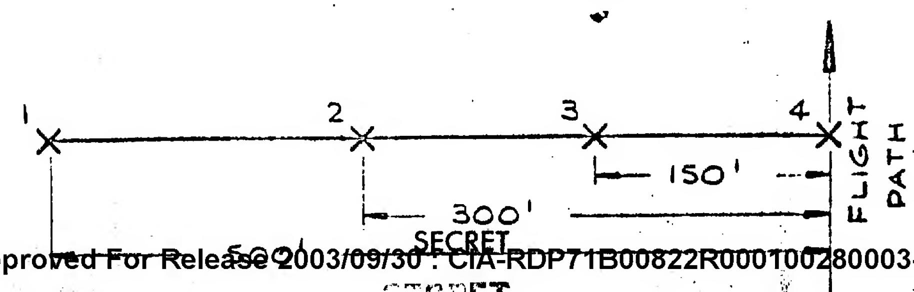
Figure 8

FIGURE 9

SLANT DISTANCES TO
600 FT. AND 1000 FT. ALTITUDES



MICROPHONE LOCATIONS



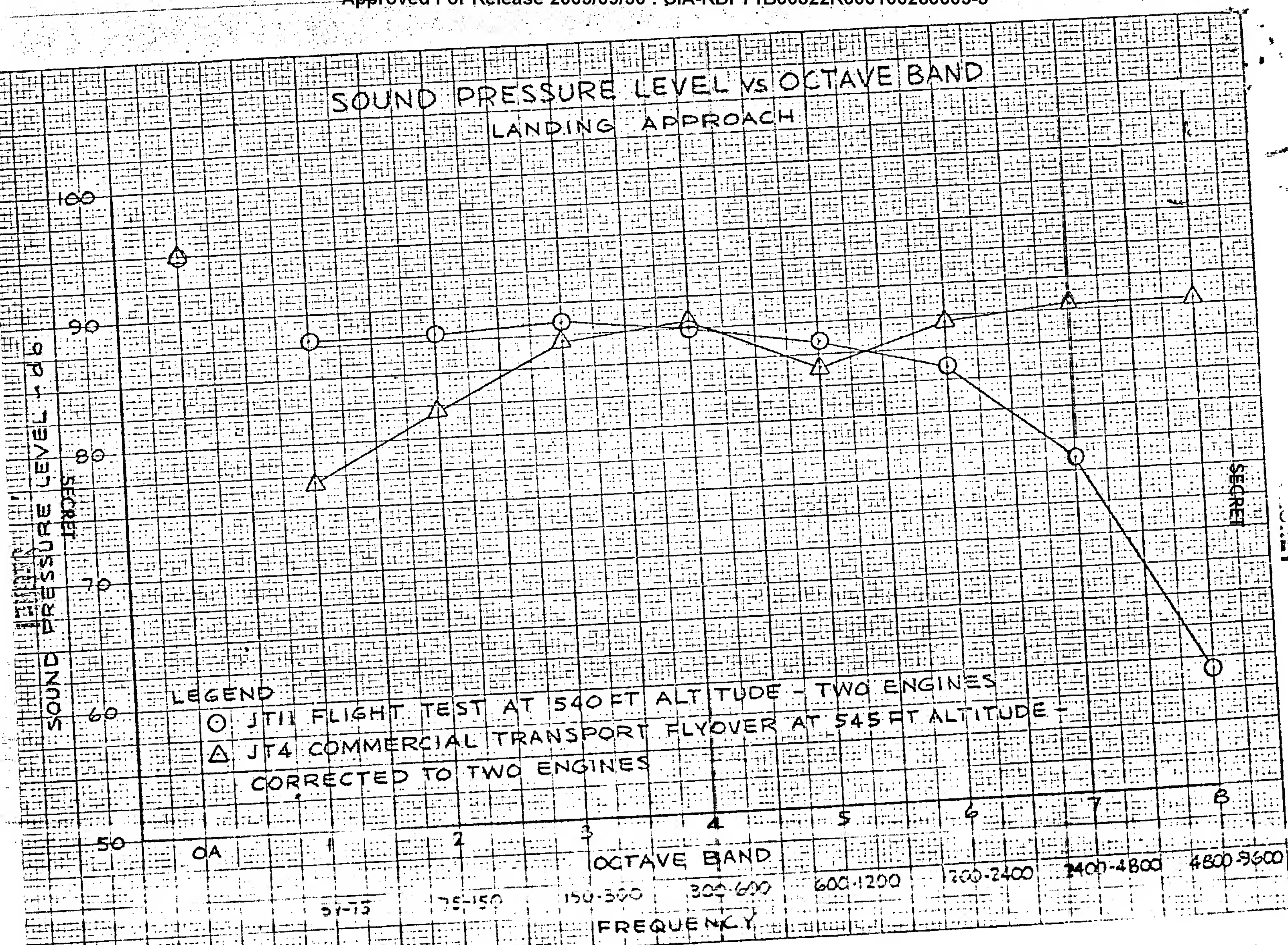


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FIGURE 10

CLASSIFICATION

SECRET

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HANDLING PROCEDURES

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